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A REPORT ON THE DEKALB COUNTY INCINERATOR STUDY

Leland E. Daniels

Bureau of Solid Waste Management
Cincinnati, Ohio

1970

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This report (SW-31ts) was written by

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Solid Waste Management
1970

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FOREWORD

Incineration is an important method of solid waste processing in the United States, and although over 300 incinerators are in operation, little information on the performance of these units is available. It is therefore not surprising that the effects of incineration on the environment are little understood and frequently ignored.

An incinerator discharges effluents into the environment in three states: solid, liquid, and gaseous. The sources of these effluents are the processes of combustion, gas cleaning, and residue quenching. Any determination of the pollution contribution to the environment by incineration must be concerned with all these effluents.

The Bureau of Solid Waste Management, through the Division of Technical Operations, has initiated a testing program to characterize the performance of incinerators of different designs and configurations. The primary objectives of this program are to produce basic information that identifies the results of the incineration process and to develop reliable sampling methodology.

During the studies it is considered necessary to make a complete analysis of all features that affect the operation of the facility as well as those that influence its potential for environmental pollution. The operation of the facility is not altered in any way unless specific

study objectives dictate a change. Therefore, no special effort is made to operate the facility at its design capacity; rather, it is tested at its "operating" capacity.

Reports from each study in this program will be prepared primarily for use by the management of the facility, although they will be available upon request to other interested technical personnel. Each report will contain only the data obtained during one individual study. Data comparisons with other studies will not be made in individual study reports. Summaries and comparisons of the data from all studies (including comparisons), will be reported annually. Persons interested in receiving these annual reports should contact the Office of Information, Bureau of Solid Waste Management, 5555 Ridge Avenue, Cincinnati, Ohio 45213.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

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A REPORT ON THE DEKALB COUNTY INCINERATOR STUDY

On October 28, 1968, the DeKalb County, Georgia, Department of Public Health, requested assistance from the Bureau of Solid Waste Management in solving the problem of excess particulate emissions from the DeKalb County incinerator. A field study of the incinerator was conducted from December 11 to 13, 1968, to determine the potential level of pollution resulting from the solid, liquid, and gaseous effluents from the incinerator. The results of this study will enable the County, through the use of a consultant, to determine what modifications to the plant and/or operation will be necessary to achieve an acceptable quality of operation.

REPORT SUMMARY

The DeKalb County incinerator is a rotary kiln incinerator with two identical combustion units, each having a design capacity of 300 tons per 24 hr. Inclined reciprocating grates are used in the drying and ignition chambers. Further combustion is achieved in the kiln and mixing chamber. The combustion products from each furnace pass through separate water scrubbers and are discharged to the atmosphere through a common stack. The residue drops from the kiln into the quench tank where a drag conveyor removes the residue and discharges it into a residue truck for removal to a land disposal operation. The wastewater from the scrubber and quench tank flows through a sedimentation basin and is discharged to a small watercourse.

Solid Waste

The principal portion of the combustibles was composed of 60.6 percent paper products and 18.3 percent food wastes. The major portion of the noncombustibles was composed of 8.5 percent metals and 5.4 percent glass and ceramics. The bulked density ranged from 95 to 190 lb per cu yd and averaged 145 lb per cu yd. During the study period, the waste received by the plant had an average moisture content (as sampled) of 21.0 percent, a volatile content (dry) of 77.3 percent,

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an ash content (dry) of 22.7 percent, and a heat content (as sampled) of 5,530 Btu per lb.

Residue

The fines averaged 79.4 percent. This can be attributed to a size reduction of the residue as a result of the tumbling action occurring in the rotary kiln. The unburned combustibles content averaged 0.7 percent, the metals averaged 16.8 percent, and the glass and rocks averaged 3.1 percent. The density of the noncompacted, water-saturated residue ranged from 1,430 to 1,885 lb per cu yd and averaged 1,615 lb per cu yd. The residue had an average moisture content (as sampled) of 24.8 percent, a volatile content (dry) of 7.3 percent, an ash content (dry) of 92.7 percent, and a heat content (dry) of 945 Btu per lb.

Plant Efficiency

The plant achieved an overall weight reduction of approximately 72 percent, a volatile reduction of approximately 97 percent, a volume reduction of approximately 97 percent, and released approximately 96 percent of the available heat.

Process Waters

During the study the process wastewaters were not measured quantitatively. However, past records showed that the plant consumption averaged 936,100 gal per day or 2,095 gal per ton of solid waste processed.

The scrubber water had a temperature of 82 F, and the pH ranged from 3.0 to 5.0. The alkalinity was 30 mg per liter, the chloride content was 185 mg per liter, the hardness was 185 mg per liter, and the phosphate content was 8.8 mg per liter. The total solids concentration was 610 mg per liter, of which 14.8 percent was suspended solids and 85.2 percent was dissolved solids.

After the scrubber water was added to the quench tank and the quenched residue was removed, this wastewater had a temperature of 68 F, and the pH ranged from 5.4 to 7.1. The hardness concentration remained nearly the same, but the alkalinity increased to 145 mg per liter, the chloride content decreased to 100 mg per liter, and the phosphate concentration increased to 13.8 mg per liter. The quench water contained 1,120 mg per liter of total solids, of which 67.9 percent were suspended solids and 32.1 percent were dissolved solids.

The lagoon effluent had a temperature of 65 F, and the pH ranged from 5.8 to 7.9. The alkalinity, chloride, and hardness concentrations remained nearly the same, but the phosphate concentration decreased to 9.3 mg per liter. The total solids concentration was 900 mg per liter, of which 63.9 percent were suspended and 36.1 percent were dissolved. Because the solids were not continuously removed, the lagoon was full of solids, and the total solids concentration was reduced only 19.6 percent by removing 24.3 percent of the suspended solids.

Burning Rate

During the study, the plant's burning rate was 354 tons per 24 hr with essentially one furnace operating (the second furnace was operated for 19 hr only), which meant that the furnaces were operating at 107 percent of available design capacity. During the previous year, the burning rate was 575 tons per 24 hr, which meant that the plant was then operating at 96 percent of plant design capacity.

Particulate Emissions

The calculated gas concentration averaged 3.9 percent carbon dioxide, 15.9 percent oxygen, and 80.2 percent nitrogen. The excess air averaged 320 percent. The measured particulate emissions averaged 0.72 gr per scf (grains per standard cubic foot) corrected to 12 percent carbon dioxide, 1.18 lb per 1,000 lb of dry flue gas corrected to 50 percent excess air, 167 lb per hour, and 12.5 lb per ton of waste charged. These values are within ± 20 percent of the true emission rates (see RESULTS).

Economic Analyses

Based upon the costs from the last fiscal year and an average burning rate of 575 tons per 24 hr, the total annual cost was $558,092, or $3.46 per ton, excluding revenue from private collectors. The direct labor cost was 29.7 percent of the total cost. The operating cost was 72.1 percent of the annual cost and the financing and ownership costs were 27.9 percent.

When the operating cost is based on cost centers, 30 percent was spent in receiving, 34 percent was spent in volume reduction, and 36 percent was spent in effluent treatment.

Bacteriological Analyses

The solid waste averaged 40×10^5 bacteria per gram and the residue averaged 27×10^2 per gram. Thus the average total bacteria count was reduced by a magnitude of 1,500. Aerobic spores were reduced by a magnitude of 2,500 and anaerobic spores by a magnitude of 1,500. The density of total coliforms and fecal coliforms isolated from the solid waste was 33.4×10^4 per gram and 14.7×10^3 per gram, respectively. Coliforms were also recovered from one sample of the quench water, but there were no isolations from the residue, stack gas, fly ash, and tapwater samples. Salmonella were not isolated from any source.

FACILITY DESCRIPTION

The DeKalb County Sanitation Department operates two landfills and one incinerator for all of the solid waste collected within Dekalb County, excluding metropolitan Atlanta. The county incinerator is centrally located on the public service area property adjacent to Memorial Drive and Interstate 285, and is surrounded by land that is zoned residential. The architectural design of the plant, the sedimentation lagoon, and the nearness of a land disposal operation do not present an attractive appearance.

The plant is of rotary kiln design with a design capacity of 600 tons per day. The incinerator was designed by International Incinerator, Inc.* and completed in November 1963. The plant has two continuous-feed furnaces with a common stack. Each combustion unit consists of three sections of inclined reciprocating grates (two drying grates and one ignition grate), a rotary kiln, a gas-mixing chamber, and a water scrubber (Figures 1 and 2).

Solid Waste Handling

Solid waste is weighed as it enters the plant and is accepted throughout the workweek from commercial, industrial, and municipal

*Mention of commercial products does not imply endorsement by the U.S. Government.

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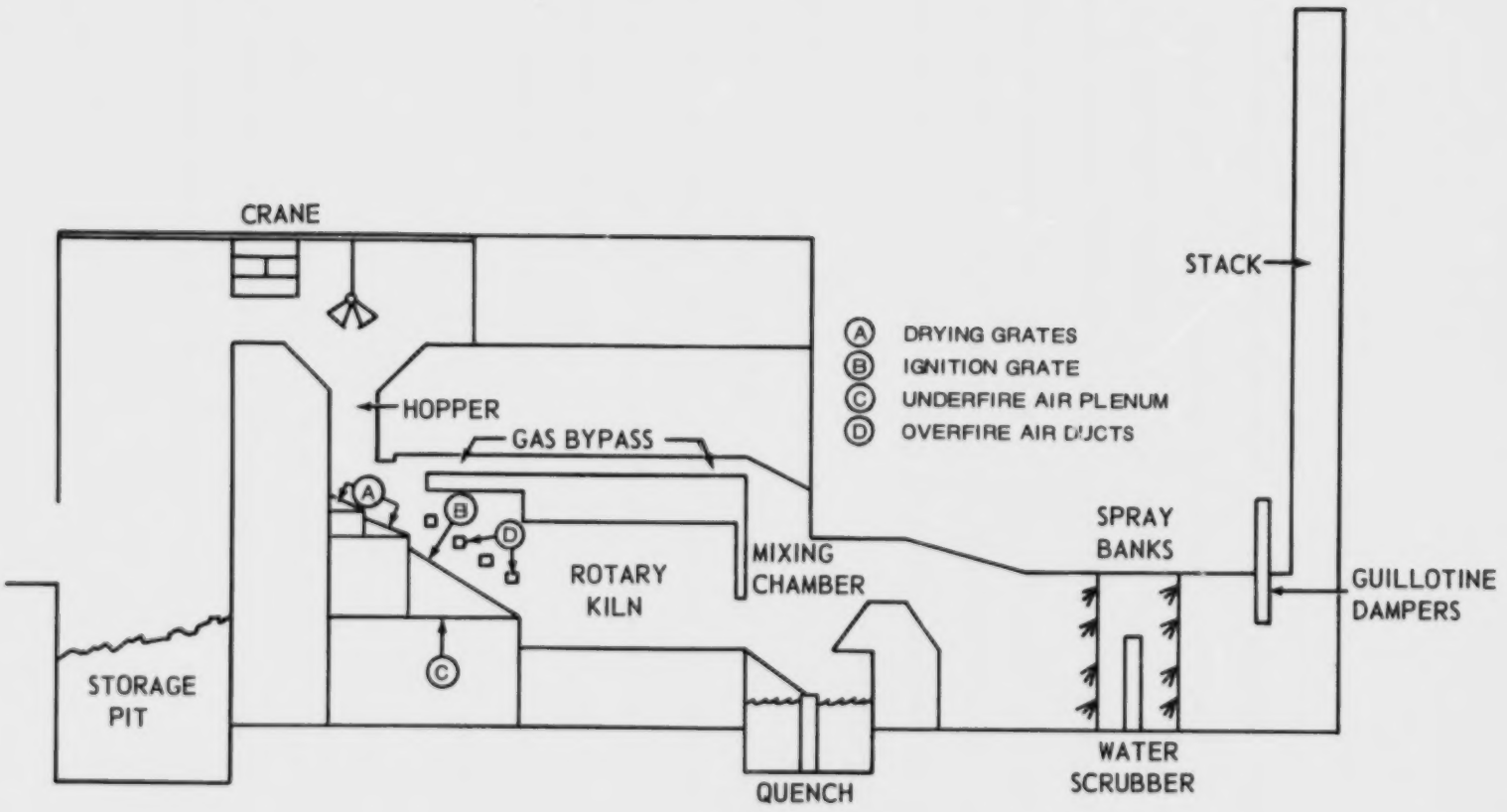

Figure 1. Schematic of DeKalb County incinerator.

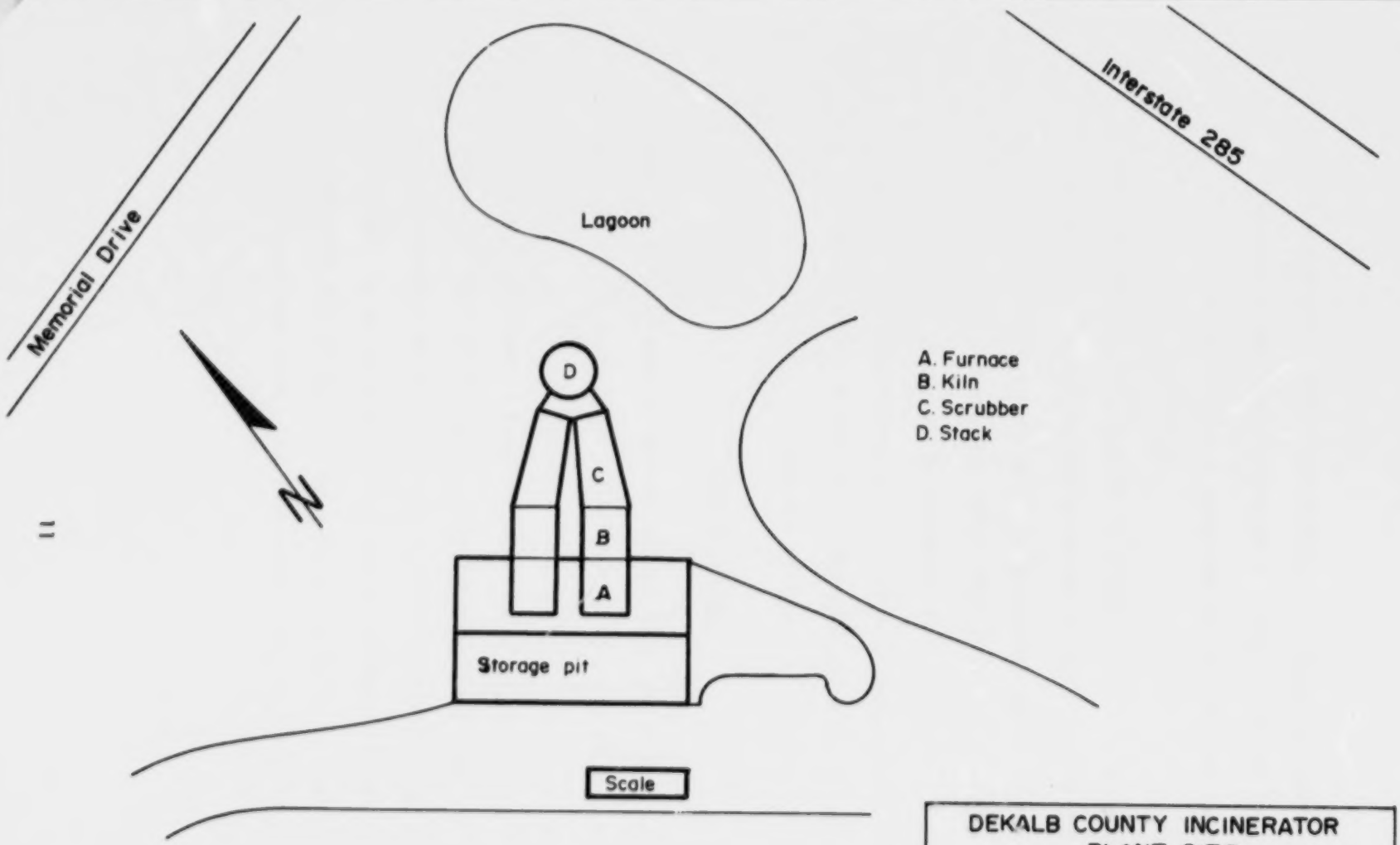

Figure 2. DeKalb County incinerator plant site.

DEKALB COUNTY INCINERATOR PLANT SITE		
U.S. Department of Health, Education and Welfare		
Public Health Service		
Bureau of Solid Waste Management		
Division of Technical Operations		
December, 1968	Figure 2	Not to scale

sources. All incoming trucks are weighed continuously to provide a weight record of the solid waste. A 30-ton Fairbanks-Morse automatic scale located at the front of the building is used to weigh the incoming trucks.

The storage pit is approximately 27 ft deep, 25¼ ft wide, and 96½ ft long and has a capacity of 2,435 cu yd when filled to the level of the tipping floor. Water sprays and ventilators are available for controlling airborne dust generated within the storage pit during dumping. Seven trucks can be accommodated at one time.

Two P & H 5-ton-capacity cranes with 3-cu-yd buckets are used to charge the hoppers. The enclosed cab is mounted on the crane and contains air-conditioning and heating systems.

Combustion Unit

Solid waste is fed to each furnace through a hopper having a cross section of 4½ by 8 ft and a depth of 19 ft. The hoppers are lined with heavy-duty refractories.

Each combustion unit (Table 1) was designed to burn 300 tons of solid waste per day. Each contains two sections of inclined reciprocating drying grates and one section of inclined reciprocating ignition grates. Siftings that fall through the drying grates are moved by an auger to the ignition grates. Siftings from the ignition grates are also moved by an auger to the quench tank. Suspended walls were used to construct the furnaces.

TABLE 1

DESIGN CHARACTERISTICS PER COMBUSTION UNIT

Unit and characteristic	Specifications
Drying grates:	
Number	2
Type	Reciprocating
Expected grate life	1½ yr
Area	114 sq ft
Volume above grates	1,240 cu ft
Drop distance between sections	10½ in.
Drop distance to ignition grate	6 ft
Type of refractory	High-duty
Expected refractory life	5 yr
Ignition grate:	
Number	1
Type	Reciprocating
Expected life	1½ yr
Area	130 sq ft
Volume above grate	1,700 cu ft
Stroke	4½ in.
Drop distance to kiln	4 ft
Type of refractory	Super-duty
Expected refractory life	5 yr
Kiln:	
Internal diameter	10 ft 10 in.
Length	30 ft
Volume	2,760 cu ft
Type of refractory	(a) First 15 ft--high-duty (b) Last 15 ft--70% alumina
Expected refractory life	(a) First 10 ft--3 yr (b) Second 10 ft--1½ yr (c) Third 10 ft--6-11 months
Slope	½ in. per ft
Gas bypass duct:	
Volume	930 cu ft
Type of refractory	Super-duty
Mixing chamber:	
Volume	3,000 cu ft
Type of refractory	Super-duty
Scrubber:	
Type of refractory	Super-duty
Expected refractory life	3 yr

Each furnace has a forced-draft fan rated at 25,000 cu ft per min at 10 in. of water static pressure. This fan supplies both the overfire and underfire air to the ignition grate. The overfire air enters the furnace over the ignition grates through ducts in the wall. The underfire air enters the furnace through the ignition grates from a plenum chamber below the grates. Manually operated dampers control the distribution of the air. Past operation has relied primarily on underfire air with occasional use of overfire air.

Approximately 35 percent of the hot gases bypass the furnace by flowing from the ignition chamber over the incoming waste for drying. The gases then flow through a bypass duct located above the drying grate to the mixing chamber where they combine with the remaining combustion gases (Figure 1).

The common stack provides the natural draft required to remove the combustion products from both furnaces. The stack is 200 ft high and has an inside diameter of 16 2/3 ft at the sampling ports. It has a 30-ft target wall lined with high-duty fireclay brick, and the remainder of the stack is lined with intermediate-duty fireclay brick. Guillotine dampers located after each scrubber are used to control the natural draft.

Residue Disposal

After passing through the kiln, the residue falls into one of the two quench tanks. A gate directs the residue into the desired tank.

A drag conveyor removes the residue from the quench tank to the residue hopper. Three trucks, each with a capacity of 5 cu yd, are used to haul the residue to a disposal site located ½ mile from the incinerator. The residue is not normally weighed as it leaves the plant.

Air Pollution Control

A water scrubber containing two banks of sprays with two partial baffle walls between them is used to reduce the fly ash emissions (Figure 1). Each spray bank contains 5 horizontal water lines. Each water line contains 11 holes 1/8 in. in diameter. Thus the water scrubber contains 110 water sprays that spray downward at a 45° angle. A layer of water is impounded on the floor of the scrubber by a standpipe. Overflow through this standpipe is continuously discharged to the quench tank. Every 4 hours, the fly ash entrained in this pool of water is sluiced to the quench tank.

Instrumentation

An instrument panel is located on the main furnace floor between the two furnaces. Instruments included are draft gauges, temperature recorders, grate speed controls, and kiln speed controls. The instrument readings are recorded hourly in a daily operation log. The total draft supplied by the forced-draft fan, the draft above the ignition grates, the draft in the mixing chamber, the draft in the scrubber, and the natural draft provided by the stack are monitored.

Temperatures are recorded from thermocouples located above the drying grates, above the ignition grate, in the mixing chamber, and at the base of the stack.

Plant Operation During Study

After 19 hr of operation on Monday of the study week, a refractory failure occurred that required one of the furnaces to be removed from operation. Because of the small capacity of the storage pit, a backlog of solid waste accumulated.

During the study period the residue was weighed as it left the plant.

SAMPLING AND TESTING PROCEDURES

This section discusses the methods used to collect and analyze the following samples: (1) solid waste, (2) residue, (3) stack particulate emissions, and (4) process water. The sample preparation for the bacteriological analysis is also described. The sampling locations (Figure 3) of the solid, liquid, and gaseous products of the incinerator were based on their flow systems and ease of sampling.

A field study of the DeKalb County incinerator was conducted from December 11 to 13, 1968, to determine the characteristics of its operation. Samples were collected according to the schedule in Table 2.

TABLE 2

SAMPLING SCHEDULE

Source	Sample number		
	Wednesday (12-11-68)	Thursday (12-12-68)	Friday (12-13-68)
Stack particulates	none	1,2,3	4
Solid waste*	1,2	3,4,5,6,7,8	none
Residue†	none	1,2	3,4
Process water‡	none	1,2,3	4

*Even-numbered samples returned to laboratory for analyses.
†All samples returned to laboratory for analyses.
‡All sources were sampled.

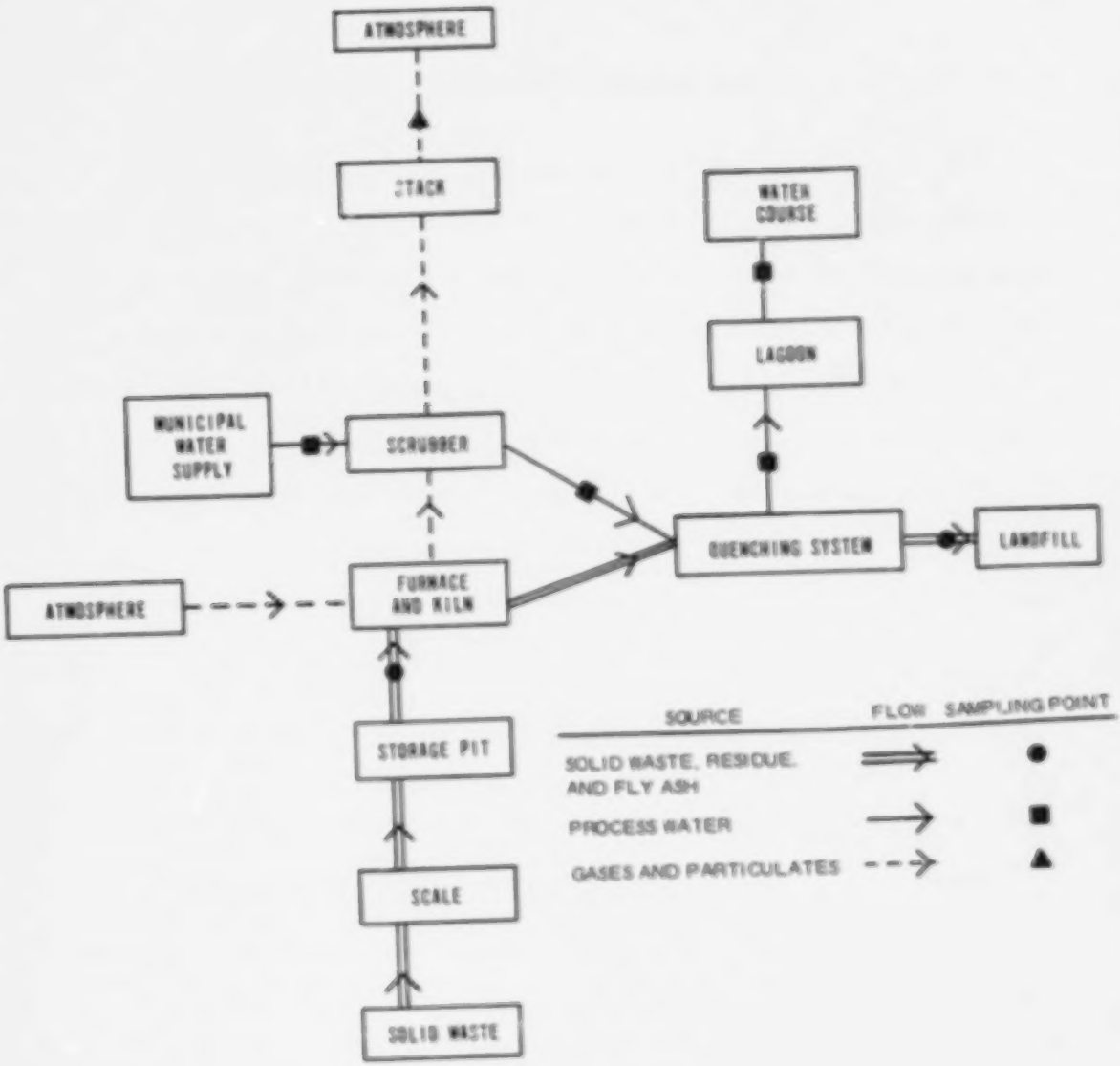

Figure 3. Flow diagram of the DeKalb County Incinerator.

Solid Waste

The amount burned during the study was calculated from the weight records of the solid waste delivered to the plant an an estimate of the amount of solid waste in the storage pit before and after the test period. The burning rate was determined by dividing this amount by the hours of operation during the week.

A total of eight samples, representative of the wastes being burned, were obtained from the storage pit. These samples were spread on a drop cloth and hand-sorted into nine categories (Table 3). Each category was weighed and the percent by weight was determined for each category on an "as received" basis. Using these percentages, 10- to 15-lb samples were reconstituted from the combustible portion for

TABLE 3

SOLID WASTE SEPARATION CATEGORIES

Combustibles*	Noncombustibles
Food waste	Metal products
Paper products	Glass and ceramics
Plastics, rubber, and leather	Ash, rocks, and dirt
Wood	
Garden waste	
Textiles	

*Determined by physical separation.

laboratory analyses. To prevent moisture loss, each of these samples was placed in two plastic bags, one inside the other, and each bag was knotted separately.

Before separation, the bulked density of the solid waste sample was obtained by filling a 0.1 cu yd container and determining the net weight. No effort was made to compact the wastes during placement in the container.

At the laboratory, the combustible portion of the solid waste sample was processed in a hammermill to reduce the maximum particle size to 1 in. The ground product was spread on a plastic sheet and thoroughly mixed. The sample was then successively mixed and quartered, and alternate quarters were discarded. This process was repeated until a sample size of 3 to 4 lb was obtained.

A 100-gram portion was dried at 70 to 75 C to constant weight to determine the moisture content.[1] The sample was then ground in a Wiley mill until it would pass through a 2-mm mesh sieve. The volatile* and ash fractions[1] and the heat content[2] were then determined. Ultimate analyses[3] for carbon, hydrogen, oxygen, nitrogen, sulfur, and chlorine were performed on the ground sample. The sample was also analyzed for ash.

Residue

Samples were collected from the residue conveyor after the stack test, spread on a drop cloth, and hand-sorted into four categories.

*Material determined by a laboratory analysis.

These categories were the unburned combustibles, fines, metals, and glass and rocks. The fines are the unidentified materials that pass through a ½-in.-mesh screen and do include metal and combustible materials. After separation, each category was weighed and the percent by weight on a wet basis for each category was determined. The fines and unburned combustibles were individually sealed in plastic bags to preserve the moisture content and were returned to the laboratory for analyses. The remaining categories were discarded.

The bulked density of the residue was obtained by filling a 0.03-cu-yd container with the samples obtained from the drag conveyor and determining the net weight. No effort was made to compact the residue during placement in the container.

At the laboratory, the fines and unburned combustibles were processed in the same fashion as the solid waste samples, but with the following exceptions: a 100-gram portion was dried at 100 to 105 C to constant weight to determine the moisture content, and benzoic acid was used as a combustion aid in the calorimeter to determine the heat content. Ultimate analyses were also performed on the ground sample.

Sample No. 2 was not separated and was returned to the laboratory intact for moisture determination only.

Particulate Emissions

On Monday, the equipment was assembled and the preliminary measurements were made on Wednesday to determine the moisture content,

carbon dioxide content, and velocity of the stack gases. Three particulate tests were conducted on Thursday and one on Friday. The sampling train and the sampling and analytical procedures used are described in "Specifications for Incinerator Testing at Federal Facilities."[4]

The sampling ports were located 66 2/3 ft above the stack foundation and approximately 180° apart. Samples were taken from the sampling ports utilizing a 24-point traverse inside the stack. The sampling ports were located 3 diameters from the top of the stack inlet and 8 diameters from the stack exit. Velocity head ranged from 0.01 to 0.08 in. of water. A 3/8-in. nozzle was used on the particulate sampling probe. Initially the sampling time was 4 min at each point. The sampling time was increased to 6 min for the last three tests.

During the test, whenever excessive accumulations of particulate on the filters hindered isokinetic sampling, the filters were replaced and the test continued.

Process Waters

Each source of process water was sampled to determine its characteristics. These sources were the incoming water (municipal water), scrubber water, scrubber sluicing water, quench water (containing scrubber water), and the plant's final effluent after passing through a lagoon.

Two grab samples from each source, except the scrubber sluicing water, were collected during each stack test. A 1-liter composite

sample based on equal portions was made from the grab samples for each source for each stack test, except for the scrubber sluicing water where only grab samples were obtained. These samples were shipped to the laboratory to be analyzed for solids,[5] alkalinity,[5] chloride,[5] hardness,[5] sulfate,[5] phosphate,[5,6] and conductivity.[5] The pH and temperature of each sample was determined in the field. A Corning pH meter, Model No. 7, was used.[7]

Economics

The cost data were obtained by checking all cost records kept by the plant and any administrative group keeping pertinent records. In addition, the personnel who maintained the cost records were questioned to verify and incorporate correctly the cost data to fit the Bureau's cost-accounting scheme.

Bacteriological Analyses

The solid waste, residue, quench water, stack gases, fly ash, and tapwater were sampled and analyzed for total bacterial count, heat-resistant spores, coliforms, salmonella, and selected respiratory pathogens.

A 200-g sample of solid waste was homogenized for 15 sec in a Waring Blendor containing 1,800 ml of phosphate-buffered water. Serial tenfold dilutions in sterile phosphate-buffered water were made through 10^{-7} after homogenization. For the solid waste, 0.1-ml aliquots from a dilution of 10^{-1} to 10^{-7} (yielding 1 log higher dilution) were pipetted

into petri dishes for total bacterial count[5] and onto prepared blood agar plates for the propogation of fastidious organisms. Ten-ml aliquots of each dilution were then transferred to tubes and heated in a waterbath at 80 C for 15 min for the testing of sporeformers.[5] In addition to aerobic spores, anaerobic spores were tested by use of anaerobic jars. One-ml aliquots from the initial dilutions used for total count and pathogen isolation were filtered through Millipore membranes for the quantitation of total and fecal coliforms.[5] The same procedures were used for the residue, except that the dilutions were pipetted from 10^{-1} through 10^{-3}.

In order to isolate salmonella,[8,9] 30 grams of material were placed into each of two different enrichment media and incubated at 41 C for 18 hr. After incubation, the enrichments were streaked onto selective enteric plates and also incubated at 41 C for 18 hr. Suspected salmonella colonies were tested for biochemical and serological reactions.[10] Selective cultures were sent to the National Communicable Disease Center, Atlanta, for serological typing of the salmonella species.

The methods used for analyzing the quench water were similar to those used for the solid waste. For the analyses of total bacterial count, sporeformers, fastidious pathogens, and coliforms, the dilutions ranged from 10^{0} to 10^{-6}. Thirty-ml aliquots of quench water were inoculated into each enteric enrichment media for salmonella. The tapwater was tested in a similar manner.

One gram of fly ash was placed into 9 ml of buffered water from which 1-ml and 0.1-ml aliquots were tested for total bacterial count, sporeformers, and respiratory pathogens.

The stack sampling device was calibrated to pull 0.62 cu ft per minute. The sampling time was 5 min for the first sample and 10 min for the second. The stack gases were forced through 300 ml of buffered water. After sampling, 100 ml of the inoculated buffered water were filtered through a membrane filter for total bacterial count. One-ml amounts were tested for sporeformers and pathogens.

RESULTS

This section presents the data obtained from the analyses of samples taken during the field study of the DeKalb County incinerator.

Solid Waste

The physical composition data (Table 4) was calculated on an "as received" basis.

The densities of the uncompacted solid waste samples were calculated on a wet basis as sampled from the storage pit. The values for samples 3 through 8 are 140, 95, 110, 170, 155, and 190 lb per cu yd, respectively. The average density was 145 lb per cu yd.

For the proximate analyses of the solid waste (Table 5), the ash and volatile fractions were calculated on a dry basis, and the heat content was calculated on an "as received" basis. Only the combustible portion was analyzed, and the results were calculated for the complete sample by assuming that the noncombustibles contained no moisture, no heat, and were considered as "ash." Example calculations are given in Appendix A.

Because the proximate and ultimate analysis data for solid waste sample No. 2 appeared significantly different when compared to the other data, these data were not used in calculating the average values.

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TABLE 4

SOLID WASTE COMPOSITION

Component	Sample number																Average percent
	1[a]		2[a]		3		4		5		6		7		8		
	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	
Combustibles:																	
Food waste	26.8	6.2	29.8	25.7	34.5	20.8	28.2	11.1	31.5	15.5	32.0	13.2	70.0	24.6	60.5	22.9	18.3
Garden waste	58.5	13.7	5.7	5.0	0.3	0.2	0.8	0.3	4.8	2.3	1.5	0.6	1.3	0.4	0.3	0.1	0.6
Paper products	134.0	31.4	32.7	28.3	95.0	57.3	195.0	76.6	120.2	54.3	168.2	69.7	144.5	50.9	137.5	52.0	60.6
Plastic, rubber, leather	9.0	2.1	7.0	6.0	4.0	2.4	4.3	1.6	2.0	1.0	5.0	2.1	6.5	2.3	8.7	3.3	2.1
Textiles	18.7	4.4	1.3	1.1	2.0	1.2	0.5	0.2	4.0	2.0	4.3	1.8	8.0	2.8	7.5	2.8	1.8
Wood	26.5	6.2	6.5	5.6	0.0	0.0	5.2	2.1	23.2	11.5	0.5	0.2	0.5	0.2	0.0	0.0	2.3
Total	---	67.0	---	71.7	---	81.9	---	91.9	---	91.6	---	87.6	---	81.2	---	81.1	85.9
Noncombustibles:																	
Metals	34.5	8.1	13.8	11.9	14.0	8.5	16.5	6.5	13.3	6.5	15.0	6.2	31.5	11.1	30.8	11.6	8.5
Glass and ceramics	8.2	4.3	17.7	15.3	16.0	9.6	2.3	0.9	1.8	0.9	13.7	5.7	21.7	7.7	19.2	7.3	5.4
Ash, rocks, dirt	100.8	23.6	1.3	1.1	0.0	0.0	1.7	0.7	2.0	1.0	1.3	0.5	0.0	0.0	0.0	0.0	0.4
Total	---	36.0	---	28.3	---	18.1	---	8.1	---	8.4	---	12.4	---	18.8	---	18.9	14.1
Grand total	427.0	100.0	115.8	100.0	165.8	100.0	254.5	100.0	202.8	100.0	241.5	100.0	284.0	100.0	264.5	100.0	100.0

[a]These samples were not used when determining average values.

TABLE 5

PROXIMATE ANALYSES OF SOLID WASTE

Sample number	Moisture, as sampled (%)	Volatiles, dry (%)	Ash, dry (%)	Heat, as sampled (Btu/lb)
2*	26.7	51.8	48.2	3,910
4	21.1	81.0	19.0	5,730
6	20.2	79.9	20.1	5,700
8	21.8	71.1	28.9	5,160
Average	21.0	77.3	22.7	5,530

*The data from this sample were not used when determining the average values.

The results from the ultimate analyses of the solid wastes (Table 6) were calculated on an "as received" basis. It was assumed that each sample contained only those elements shown, and the results were accordingly adjusted on a weight basis to 100 percent.

Residue

The residue separation data (Table 7) were calculated on an "as sampled" basis.

The densities of the uncompacted residue samples were calculated on a wet basis as sampled from the conveyor. The densities of samples 1, 3, and 4 were 1,530, 1,885, and 1,430 lb per cu yd, respectively. The average density was 1,615 lb per cu yd.

TABLE 6

ULTIMATE ANALYSES OF SOLID WASTE
(Percent)

Sample number	Moisture	Inerts	Carbon	Hydrogen	Oxygen	Sulfur	Chlorine	Nitrogen	Total
2*	26.7	35.3	18.9	2.5	15.8	0.1	0.2	0.5	100.0
4	21.1	13.5	32.2	5.8	26.3	0.2	0.4	0.4	100.0
6	20.2	15.8	29.6	2.8	30.9	0.1	0.2	0.4	100.0
8	21.8	22.1	28.4	4.9	21.9	0.1	0.2	0.6	100.0
Average	21.0	17.7	30.1	4.0	26.4	0.1	0.2	0.5	100.0

*This sample was not used when determining average values.

TABLE 7

RESIDUE COMPOSITION

Component	Sample number*						Average percent
	1		3		4		
	lb	%	lb	%	lb	%	
Fines	63.8	80.4	74.7	77.6	56.0	80.2	79.4
Unburned combustibles	1.0	1.3	0.3	0.3	0.3	0.4	0.7
Metals	14.0	17.7	18.0	18.7	9.7	14.0	16.8
Glass and ceramics	0.5	0.6	3.2	3.4	3.8	5.4	3.1
Total	79.3	100.0	96.2	100.0	69.8	100.0	100.0

*Sample No. 1 was collected on 12-12-68; samples 3 and 4 were collected on 12-13-68.

The proximate analyses data for the complete sample (Table 8) were calculated from the analyses of the fines and unburned combustibles. The moisture content is only representative of the sampling location, which was the residue conveyor. The percent of volatiles and heat content were calculated on a dry basis by assuming that the glass and metals contained no moisture, no heat, and were considered as "ash." Sample No. 2 was not separated and was analyzed only for moisture. Example calculations are presented in Appendix B.

TABLE 8

PROXIMATE ANALYSES OF RESIDUE

Sample number	Component			
	As sampled	Dry		
	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
1	37.4	8.5	91.5	1,335
2*	20.8	---	---	---
3	26.3	3.4	96.6	570
4	14.9	10.0	90.0	930
Average	24.8	7.3	92.7	945

*This sample was analyzed for moisture only.

The data from the ultimate analyses of the residue (Table 9) were adjusted to a dry basis by assuming that each sample contained only the seven constituents reported, and the results were adjusted accordingly on a weight basis to 100 percent.

TABLE 9

ULTIMATE ANALYSES OF RESIDUE
(Percent)

Sample number	Inerts	Carbon	Hydrogen	Oxygen	Sulfur	Chlorine	Nitrogen	Total
1	88.2	11.3	0.2	0.0	0.2	0.0	0.1	100.0
3	94.4	5.0	0.3	0.0	0.2	0.0	0.1	100.0
4	91.8	7.8	0.1	0.0	0.2	0.0	0.1	100.0
Average	91.5	8.0	0.2	0.0	0.2	0.0	0.1	100.0

Plant Efficiency

An indication of the plant's performance is obtained by calculating the percent of weight reduction, volatile reduction, heat released, and volume reduction (Table 10). These calculations are shown in Appendix C.

TABLE 10

PLANT EFFICIENCY

Efficiency	Percent
Weight reduction	72
Volatile reduction	97
Heat released	96
Volume reduction	97

Samples of the particulates and wastewater solids were not analyzed for ash, volatiles, or heat content. The wastewater flow also was not

measured. Because these values were not used in the plant efficiency calculations, the efficiencies shown are slightly higher than they would have been if these values had been included.

The dry weights of the solid waste, residue, and particulates were used to calculate the percent of weight reduction. The percent of volatile reduction was also calculated on a dry basis by using the solid waste and residue data. The percent of heat released was calculated with the residue data on a dry basis, and the solid waste data on an "as received" basis. The percent of volume reduction was calculated from the wet density values and the total weights of solid waste and residue.

Process Waters

It was impossible to obtain a sample of the quench water because the scrubber water was continuously discharged into the quench tank. The data (Tables 11 and 12) for the quench water were obtained from the analyses of this mixture of scrubber water and quench water. This mixture was the final effluent from the combustion process. After removal of the heavy solids in a lagoon, this process water was discharged to a small watercourse.

Instrument Readings

During the stack tests, the instrument panel was monitored to provide information about the plant's operation. Temperatures throughout the combustion unit were monitored at several points. The preheated

TABLE 11

AVERAGE CHEMICAL CHARACTERISTICS OF WASTEWATER

Source	pH	Temperature (F)	Alkalinity (mg/l $CaCO_3$)	Chloride (mg/l)	Hardness (mg/l $CaCO_3$)	Sulfate (mg/l SO_4)	Phosphate (mg/l PO_4)	Conductivity (μmhos/cm)
Plant influent	5.9	---	75	5	45	5	0.2	45
Scrubber water	3.0-5.0	82	30	185	185	25	8.8	630
Scrubber sluicing water	5.0-7.4	68	1,800	125	230	45	180.0	460
Quench tank effluent	5.4-7.1	68	145	100	175	45	13.8	525
Lagoon effluent	5.8-7.9	65	140	95	185	---	9.3	435

TABLE 12

AVERAGE SOLIDS CONCENTRATION OF WASTEWATER

Source	Total solids					Suspended solids					Dissolved solids (mg/l)
	Total mg/l	Volatiles		Ash		Total mg/l	Volatiles		Ash		
		mg/l	%	mg/l	%		mg/l	%	mg/l	%	
Plant influent	75	60	80.0	15	20.0	0	0	0.0	0	0.0	75
Scrubber water	610	215	35.2	395	64.8	90	20	22.2	70	77.8	520
Sluicing water from scrubber	8,710	1,370	15.7	7,340	84.3	8,230	1,185	14.4	7,045	85.6	480
Quench tank effluent	1,120	420	37.5	700	62.5	760	300	39.5	460	60.5	360
Lagoon effluent	900	370	41.1	530	58.9	575	220	38.3	355	61.7	325

air used to dry the solid waste averaged 250 F. The average operating temperature in the ignition chamber and mixing chamber was 1,865 F and 1,885 F, respectively. The temperature in the scrubber after the sprays averaged 485 F. Ambient air flowing through the furnace down for repairs diluted the combustion products from the furnace in operation. Because this dilution occurred after the scrubber, the temperature of the gases measured at the stack sampling location was reduced to 365 F.

Burning Rate

During the study week, 2,300 tons of solid waste were processed in 172 hr of operation and 660 tons of wet residue remained. The average daily burning rate of the plant, assuming a 6½ day operation, was 354 tons per 24 hr, 14.8 tons per hr, or 59 percent of plant design capacity. Because one furnace was operated 153 hr and the other only 19 hr during the study week, the furnace burning rate was 320 tons per 24 hr, 13.4 tons per hr, or 107 percent of the available furnace design capacity. During the previous fiscal year, the plant burned 161,166 tons during 280 operating days for an average of 575 tons per 24 hr, 24.0 tons per hr, or 96 percent of the plant design capacity. Because only one furnace was in operation during the stack tests, a burning rate of 13.4 tons per hour was used in all calculations.

Particulate Emissions

During the stack tests, the Orsat apparatus malfunctioned and could not be repaired before completion of the study. Analyses of

the stack gases, therefore, could not be made. Ultimate analyses were performed on the solid waste and residue samples, and the gaseous products of combustion were calculated. From these combustion products, the concentrations of the major gases in the stack were calculated by assuming a 20-percent reduction[11] of carbon dioxide in the water scrubber. An example calculation is presented in Appendix D. These calculated products of combustion (Table 13) were then used to adjust particulate emission concentrations (Table 14) to standard conditions. The particulate emissions include the weight of material remaining after evaporation of the impinger water.

TABLE 13

STACK TEST CONDITIONS

Test No. and date	Length of test (min)	Calculated stack gas composition (percent)				
		CO_2	O_2	CO	N_2	Excess air
1 (12-12-68)	97	5.0	14.5	0.0	80.5	215
2 (12-12-68)	144	3.7	16.2	0.0	80.1	330
3 (12-12-68)	136	3.2	16.8	0.0	80.0	390
4 (12-13-68)	144	3.7	16.2	0.0	80.1	325
Average	---	3.9	15.9	0.0	80.2	320

TABLE 14

SUMMARY OF PARTICULATE EMISSIONS

Test no.	Particulates							
	gr/scf			lb/1,000 lb dry flue gas			lb/ton waste	lb/hr
	At existing CO_2	At 12% CO_2	At 50% excess air	At existing CO_2	At 12% CO_2	At 50% excess air		
1	0.28	0.68	0.59	0.53	1.27	1.11	11.8	158
2	0.15	0.47	0.42	0.28	0.89	0.78	8.3	111
3	0.24	0.90	0.79	0.45	1.70	1.48	15.6	209
4	0.25	0.82	0.72	0.47	1.54	1.35	14.2	190
Average	0.23	0.72	0.63	0.43	1.10	1.18	12.5	167

The flow rates of the stack gases measured during the study when one furnace was inoperative were comparable to those expected when both furnaces were operating, which means that ambient air was being pulled through the inoperative furnace. It was not possible to isolate this inoperative unit. The ambient air from the inoperative furnace and the products of combustion from the operative furnace were mixed at the base of the stack. Thus, the calculated products of combustion are representative of the gases in the stack, but not of the gases in the operative furnace. This decreased the carbon dioxide concentration, increased the excess air, and diluted the particulate emissions before correction to standard conditions.

In addition to the ambient air being pulled through the inoperative furnace, some particulates were entrained in this air from the rebricking and cleaning operations. It was not possible to measure the quantity of entrained particulates from the inoperative furnace. However, in our opinion, the measured and reported particulate emissions are within ± 20 percent of values representative of the operating furnace.

The National Air Pollution Control Administration (NAPCA) indicated that approximately 20 percent of the carbon dioxide is removed when combustion gases are passed through water scrubbers.[11] Taking this removal into account results in a higher adjusted grain loading than would have occurred if all the carbon dioxide had passed through the scrubber (0.72 gr/scf at 12 percent CO_2 with CO_2 removal versus 0.57 without CO_2 removal). The NAPCA recommended that no adjustment be allowed for this reduction in carbon dioxide content.

Economic Analyses

The annual cost of the incinerator (Table 15) was based on a 1-year time period from July 1967 to July 1968. The costs are shown as operating costs and financing and ownership costs in terms of actual cost, cost per ton (based on 575 tons per 24 hr), and percent of annual cost.

The financing and ownership costs were based on a capital cost of $2.4 million and a plant life of 30 years. The plant depreciation was calculated on a straight-line basis by dividing the capital cost by the plant life. Financing was accomplished by issuing a 30-year bond at an interest rate of 3.2 percent. The cost per ton was based on a yearly tonnage of 161,166 tons processed in 280 operating days, or 575 tons per 24 hr.

TABLE 15

ANNUAL COST ANALYSES

Item	Cost	Cost per ton	Percent of annual cost
Operating costs:			
Direct labor and fringe benefits	$165,684	$1.03	29.7
Utilities (gas, electric, sewage, etc.)	67,632	0.42	12.1
Parts and supplies	51,540	0.32	9.2
Vehicle operating expenses	9,600	0.06	1.7
External repair charges	12,758	0.08	2.3
Disposal charges	10,364	0.06	1.9
Overhead	84,674	0.52	15.2
Total	402,252	2.49	72.1
Financing and ownership costs:			
Plant depreciation	80,000	0.50	14.3
Interest	75,840	0.47	13.6
Total	155,840	0.97	27.9
Total annual cost	558,092	3.46	100.0

Several items in the annual cost analyses (Table 15) need further explanation. The direct labor cost includes only the salaries of the 30 employees used in the operation of the incinerator. The salaries of the remaining nine employees used in management and plant site improvement are shown in the overhead. Because the plant was built on land previously owned by the county and no additional expenses for land were required, the cost of the land is not included. Also excluded is the revenue received from private contractors who dumped waste at the incinerator. They were charged $1.00 per ton; thus the incinerator received a revenue of $55,965.

The cost of repairs and maintenance and its allocation to the cost centers are calculated in Tables 16 and 17.

TABLE 16

COST OF REPAIRS AND MAINTENANCE

Item	Cost
Labor	$31,679
Parts	51,540
External charges	12,758
Overhead	16,189
Total	112,166

TABLE 17

ALLOCATIONS FOR REPAIRS AND MAINTENANCE

Cost center	Allocation	Percent of total
Receiving	$17,960	16.0
Volume reduction	77,804	69.4
Effluent treatment	16,402	14.6
Total	112,166	100.0

The annual operating cost (Table 18) was allocated to the following cost centers: receiving, which includes items associated with the storage pit, crane, and scale operations; volume reduction, which includes items associated with the furnace operation; and effluent treatment, which includes items associated with the residue disposal, air pollution control, and wastewater treatment operations. Allocation of the operating costs into cost centers was achieved through the use of physical factors such as the number of people involved, power requirements, and the time and material used in each cost center.

TABLE 18

OPERATING COST BY COST CENTERS

Cost center	Operating cost	Percent of total operating cost	Percent of annual cost
Receiving:			
Direct labor	$59,294	14.7	10.7
Utilities	12,715	3.2	2.3
Vehicle operating expenses	0	0.0	0.0
Repairs and maintenance	17,960	4.5	3.2
Overhead	30,302	7.5	5.4
Total	120,271	29.9	21.6
Volume reduction:			
Direct labor	34,226	8.5	6.1
Utilities	8,251	2.1	1.6
Repairs and maintenance	77,804	19.3	13.9
Overhead	17,492	4.3	3.1
Total	137,773	34.2	24.7
Effluent treatment:			
Direct labor	40,485	10.1	7.2
Utilities	46,666	11.6	8.4
Vehicle operating expenses	9,600	2.4	1.7
Disposal charges	10,364	2.6	1.9
Repairs and maintenance	16,402	4.1	2.9
Overhead	20,691	5.1	3.7
Total	144,208	35.9	25.8
Total operating cost	402,252	100.0	72.1

The labor costs in the projected annual cost at design capacity (Table 19) remain the same, because the plant is fully staffed. The financing and ownership costs also remain the same, because the expected plant life is 30 years. Again, the revenue from private contractors was not included.

TABLE 19

PROJECTED ANNUAL COST AT DESIGN CAPACITY

Item	Cost	Cost per ton	Percent of projected annual cost
Operating cost:			
Direct labor	$165,686	0.99	29.3
Utilities	70,499	0.42	12.5
Parts and supplies	53,725	0.32	9.5
Vehicle operating expenses	10,007	0.06	1.8
External repair charges	13,298	0.08	2.4
Disposal charges	10,803	0.06	1.9
Overhead	84,674	0.50	15.0
Total	408,692	2.43	72.4
Financing and ownership costs:			
Plant depreciation	80,000	0.48	14.2
Interest	75,840	0.45	13.4
Total	155,840	0.93	27.6
Total projected annual cost	564,532	3.36	100.0

Bacteriological Analyses

Samples of solid waste, residue, quench water, stack gases, and fly ash were analyzed for total bacteria, sporeformers, coliforms, salmonella, and selected respiratory organisms (Tables 20 and 21).

TABLE 20

BACTERIOLOGICAL DATA

Source and date	Total count			Aerobic spores			Anaerobic spores		
	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count
Solid waste:									
12-12-68	10^{-5}	14	14×10^5/g	10^{-2}	78	78×10^2/g	10^{-2}	70	70×10^2/g
12-13-68	10^{-5}	66	66×10^5/g	10^{-3}	43	430×10^2/g	10^{-3}	23	230×10^2/g
Residue:									
12-12-68	10^{-2}	36	36×10^2/g	10^{-1}	0	<10/g	10^{-1}	0	<10/g
12-13-68	10^{-2}	18	18×10^2/g	10^{-1}	1	10/g	10^{-1}	0	<10/g
Quench water:									
12-12-68	10^{-1}	64	64×10^3/100ml	10^0	1	100/100ml	10^0	0	<100/100ml
12-13-68	10^{-1}	22	220×10^3/100ml	10^0	2	200/100ml	10^0	0	<100/100ml
Stack:									
12-12-68*									
12-13-68	10^0	1	<0.976/cu ft	10^0	0	<97.6/cu ft	10^0	0	<97.6/cu ft
Fly ash:									
12-12-68	10^{-1}	0	<10/g	10^{-1}	1	10/g	10^{-1}	0	<10/g
12-13-68*									
Tapwater:									
12-12-68	10^0	0	<100/100ml	10^0	0	<100/100ml	10^0	0	<100/100ml
12-13-68*									

*No sample collected.

TABLE 21

COLIFORM DATA

Source and date	Total coliforms			Fecal coliforms			Salmonella
	Dilution	Plate count	Calculated count	Dilution	Plate count	Calculated count	
Solid waste:							
12-12-68	10^{-3}	19	19×10^3/g	10^{-2}	14	14×10^2/g	(*)
12-13-68	10^{-4}	65	650×10^3/g	10^{-3}	28	280×10^2/g	(†)
Residue:							
12-12-68	10^{-2}	0	<100/g	10^{-2}	0	<100/g	(*)
12-13-68	10^{-1}	0	<10/g	10^{-1}	0	<10/g	(†)
Quench water:							
12-12-68	10^0	1	100/100ml	10^0	0	<100/100ml	(*)
12-13-68	10^0	0	<100/100ml	10^0	0	<100/100ml	(†)
Stack:							
12-12-68‡							
12-13-68	10^0	0	<97.6/cu ft	10^0	0	<97.6/cu ft	(*)
Fly ash:							
12-12-68	10^{-2}	0	<100/g	10^{-2}	0	<100/g	(*)
12-13-68†							
Tapwater:							
12-12-68	10^0	0	<10/100ml	10^0	0	<10/100ml	(*)
12-13-68‡							

*None isolated.
†No test performed.
‡No sample collected.

Other isolations from the solid waste samples were the Alkalescenes--Dispar Group and *staphylococcus aureus hemolyticus*. Alpha hemolytic streptococcus was isolated from the stack gas sample.

The quench water and tapwater data are expressed as density per 100 ml of sample. When no colonies were isolated the densities were expressed as less than 100 per 100 ml of sample.

The total bacterial count was done by the membrane-filter method, and 100 ml of the inoculated buffered water sample were tested. When equated to cubic feet of stack gas, the quantitative result is expressed as equal to or less than 0.976 cu ft when the sampling time was 5 min.

A maximum of 1 ml of the buffered water sample could be tested by use of the pour plate for the sporeformers. The quantitative value is expressed as equal to or less than 97.6 per cu ft of stack gas when the sampling time was 5 min.

DISCUSSION

Last year the plant burned 65 percent of the solid waste collected within DeKalb County, with the exception of metropolitan Atlanta. This averaged 575 tons per 24 hr, which is 96 percent of the plant's design capacity. With an average annual increase in tonnage of 6 percent, the plant will reach design capacity during 1969.

The extremely small capacity of the storage pit (approximately 420 tons) does not allow sufficient time for normal repairs and maintenance of the combustion units. For example, if a repair requires a unit to be out of operation for a day, solid waste accumulates and overflows the pit, thereby hindering dumping operations, adversely affecting the appearance of the plant, and requiring extra manpower for cleanup purposes. When this condition occurs, some of the solid waste is diverted to the land disposal operations. However, insufficient quantities of waste are diverted to alleviate this problem.

The particulate emissions to the atmosphere are high (0.72 gr per scf of dry flue gas corrected to 12% CO_2) when compared to existing codes, such as the code for incinerators at Federal facilities (0.2 gr per scf of dry flue gas corrected to 12% CO_2). To reduce these emissions to meet such a code would require a more efficient particulate collector and/or modifications to existing operational procedures.

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The concentrations of pollutants within the wastewater discharged to the watercourse were high (total solids, 900 mg per liter and suspended solids, 575 mg per liter). These conditions indicate that the lagoon should be dredged periodically to increase the detention time for efficient removal.

Complaints from the public about an incinerator can be caused by a poor aesthetic appearance regardless of the quality of operation. This facility presents an unattractive appearance because the dredgings from the lagoon are left beside the lagoon rather than removed from the facility site. The unattractiveness of the facility is also caused by equipment and replaced parts from the furnaces lying on the facility grounds. In addition, when the pit overflows with waste, these wastes spill on the tipping area, which is in public view.

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Members of the field study team were as follows:

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APPENDICES

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APPENDIX A

Example Calculations for the Ash, Volatile, and Heat Content of the Solid Waste

Using the data from the laboratory analyses of solid waste sample No. 4, these example calculations show the methods used to calculate the moisture content, ash and volatile content, and the heat content of the total sample. Data received from the analyses of the solid waste samples returned to the laboratory are presented in Table A-1. The volatile and ash fractions and the heat content are on a dry basis. For these calculations, the assumptions were made that the noncombustibles contained no moisture, no heat, and were considered as "ash."

TABLE A-1

PROXIMATE ANALYSES OF THE COMBUSTIBLE PORTION OF THE SOLID WASTE SAMPLES

Sample number	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
2*	37.3	84.5	15.5	8,690
4	23.0	90.2	9.8	8,085
6	23.1	94.7	5.3	8,450
8	26.9	93.8	6.2	8,705
Average	24.3	92.9	7.1	8,415

*The data from this sample were not included when the average values were determined (see RESULTS).

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The field separation determined a combustible content of 91.9 percent (Text Table 4) on a wet-weight basis. Because the moisture in the total sample was assumed to be in the combustible portion only, the percent of moisture in the total sample was calculated by the following method:

$$\text{Percent moisture in total sample} = \left(\frac{\text{lb combustibles}}{\text{lb waste}}\right)\left(\frac{\text{lb moisture}}{\text{lb combustibles}}\right) 100.0$$

$$\text{Percent moisture in total sample (No. 4)} = (0.919)\ (0.23)\ 100.0 = 21.1$$

Because the volatile and ash fractions are calculated on a dry basis, the percent combustibles must be converted to a dry basis by means of the following equation:

$$\text{Percent dry component} = \left(\frac{\text{lb wet component minus lb moisture in component}}{\text{dry sample weight}}\right) 100.0$$

These calculations are summarized in Table A-2.

TABLE A-2

CONVERSION OF THE COMBUSTIBLE AND NONCOMBUSTIBLE DATA TO A DRY BASIS

Component	Wet weight (lb)	Percent by wet weight	Moisture		Dry weight (lb)	Percent by dry weight
			%	lb		
Combustibles	234.0	91.9	23.0	53.8	180.2	89.3
Noncombustibles	20.5	8.1	0.0*	0.0	20.5	70.2
Total sample	254.5	100.0	21.1	53.8	200.7	100.0

*Assumed.

The percent volatiles and ash may be calculated as follows:

$$\text{Percent volatiles in total sample} = \left(\frac{\text{lb volatiles}}{\text{lb dry combustibles}}\right)\left(\frac{\text{lb dry combustibles}}{\text{lb dry waste}}\right) 100.0$$

$$\text{Percent volatiles in total sample (No. 4)} = (0.902)\ (0.898)\ 100.0 = 81.0$$

$$\text{Percent ash in total sample} = 100.0 - \text{percent volatiles}$$

$$\text{Percent ash in total sample (No. 4)} = 100.0 - 81.0 = 19.0$$

The laboratory reports the heat content on a dry basis for the combustibles only. Thus the moisture content and the noncombustibles in the total sample must be accounted for when calculating the heat content of the total sample on an "as received" basis.

$$\text{Heat content of total sample} = \left(\frac{\text{Btu}}{\text{lb dry combustibles}}\right)\left[1 - \left(\frac{\text{Percent moisture in total sample}}{100.0} + \frac{\text{Percent noncombustibles of total sample}}{100.0}\right)\right]$$

$$\text{Heat content of total sample (No. 4)} = (8{,}035)\left[1.0 - \left(\frac{21.1 + 8.1}{100.0}\right)\right] = 5{,}725\ \left(\frac{\text{Btu}}{\text{lb waste}}\right)$$

APPENDIX B

Example Calculations for the Ash, Volatile, and Heat Content of the Residue

Using the data from the laboratory analyses of residue sample No. 1, these example calculations show the methods used to calculate the moisture content, ash and volatile content, and the heat content of the total sample. Table B-1 presents the laboratory data received from the analyses of the portions of each residue sample returned to the laboratory. For each sample, only the fines and unburned combustibles were returned. The volatile and ash fractions and the heat content are on a dry basis.

TABLE B-1

PROXIMATE ANALYSES OF THE UNBURNED COMBUSTIBLES AND FINES

Sample number	Unburned combustibles				Fines			
	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)	Moisture (%)	Volatiles (%)	Ash (%)	Heat (Btu/lb)
1	39.2	36.0	64.0	3,775	45.9	11.6	88.4	1,875
3	81.1	68.8	31.2	8,200	33.5	4.7	95.3	800
4	68.9	56.5	43.5	7,395	18.3	7.7	92.3	1,200
Average	63.1	53.8	46.2	6,455	32.6	8.0	92.0	1,290

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The amount of fines and unburned combustibles found during the field separation was 80.4 and 1.3 percent, respectively, on a wet-weight basis. The assumptions were made that the glass and rocks and metals contained no moisture, no heat, and were considered as "ash."

Because the moisture in the total sample was assumed to be in the fines and unburned combustibles, the percent moisture in the total sample is calculated by the following method:

$$\text{Percent moisture in total sample} = \left[\left(\frac{\text{lb fines}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb fines}}\right) + \left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)\left(\frac{\text{lb moisture}}{\text{lb unburned combustibles}}\right)\right] 100.0$$

$$\text{Percent moisture in total sample (No. 1)} = [(0.804)(0.459) + (0.013)(0.392)]\ 100.0$$

$$\text{Percent moisture in total sample (No. 1)} = 37.4$$

Because the remaining calculations are on a dry basis, the separation data from Text Table 7 must be converted to a dry basis by the following method:

$$\text{Percent dry component} = \left(\frac{\text{lb wet component minus lb moisture in wet component}}{\text{total dry sample weight}}\right) 100.0$$

These calculations are summarized in the following table:

TABLE B-2

CONVERSION OF THE RESIDUE DATA TO A DRY BASIS

Component	Wet weight (lb)	Moisture %	Moisture lb	Dry weight (lb)	Percent by dry weight
Fines	63.8	45.9	29.3	34.5	69.6
Unburned combustibles	1.0	39.2	0.4	0.6	1.2
Glass and rocks	0.5	0.0*	0.0	0.5	1.0
Metal	14.0	0.0*	0.0	14.0	28.2
Total sample	79.3	37.4	29.7	49.6	100.0

*Assumed.

The percent volatiles and ash are calculated for the total sample by the following method:

$$\text{Percent volatiles in total sample} = \left[\left(\frac{\text{lb volatiles}}{\text{lb dry fines}}\right)\left(\frac{\text{lb dry fines}}{\text{lb dry residue}}\right) + \left(\frac{\text{lb volatiles}}{\text{lb dry unburned combustibles}}\right)\left(\frac{\text{lb dry unburned combustibles}}{\text{lb dry residue}}\right)\right] 100.0$$

$$\text{Percent volatiles in total sample (No. 1)} = [(0.116)(0.696) + (0.36)(0.012)]\ 100.0$$

$$\text{Percent volatiles in total sample (No. 1)} = 8.5$$

$$\text{Percent ash in total sample} = 100.0 - \text{percent volatiles}$$

$$\text{Percent ash in total sample (No. 1)} = 100.0 - 8.5 = 91.5$$

The heat content is calculated on a dry basis by the following method:

$$\text{Heat content in total sample} = \left[\left(\frac{\text{Btu}}{\text{lb fines}}\right)\left(\frac{\text{lb fines}}{\text{lb residue}}\right) + \left(\frac{\text{Btu}}{\text{lb unburned combustibles}}\right)\left(\frac{\text{lb unburned combustibles}}{\text{lb residue}}\right)\right]$$

$$\text{Heat content in total sample (No. 1)} = (1{,}875)(0.696) + (3{,}775)(0.012) = 1{,}335\ \left(\frac{\text{Btu}}{\text{lb residue}}\right)$$

APPENDIX C

Plant Efficiency Calculations

These calculations show the methods used to determine the percent of weight reduction, the percent of volatile reduction, the percent of heat released, and the percent of volume reduction. The following data are given:

Residue:	Particulates:	Solid waste:
660 tons (wet)	167 lb per hr	2,300 tons (wet)
500 tons (dry)		1,820 tons (dry)
24.8 percent moisture		21.0 percent moisture
7.3 percent volatiles (dry)		77.3 percent volatiles (dry)
945 Btu per lb		5,530 Btu per lb
1,615 lb per cu yd		145 lb per cu yd
172 hr of burning time		

$$\text{Percent weight reduction} = \left[1 - \left(\frac{\text{dry residue wt} + \text{dry particulate wt}}{\text{dry solid waste wt}} + \frac{\text{dry wt of wastewater solids}^{a}}{\text{dry solid waste wt}}\right)\right] 100.0$$

$$\text{Percent weight reduction} = \left[1 - \left(\frac{500 + \frac{167\ (172)}{2,000}}{1,820}\right)\right] 100.0$$

$$\text{Percent weight reduction} = \left[1 - \left(\frac{514}{1,820}\right)\right] 100.0 = 71.7$$

[a] Not measured.

$$\text{Percent volatile reduction} = \left\{1 - \left[\left(\frac{\text{volatile wt in residue} + \text{volatile wt in particulates*}}{\text{volatile wt in solid waste}}\right) + \left(\frac{\text{volatile wt in wastewater solids*}}{\text{volatile wt in solid waste}}\right)\right]\right\} 100.0$$

$$\text{Percent volatile reduction} = \left\{1 - \left[\frac{(0.073)(500)}{(0.773)(1{,}820)}\right]\right\} 100.0$$

$$\text{Percent volatile reduction} = \left[1 - \left(\frac{36}{1{,}407}\right)\right] 100.0 = 97.4$$

$$\text{Percent heat released} = \left\{1 - \left[\left(\text{heat content of residue} \times \text{wt of residue} + \text{heat content of particulates*} \times \text{wt of particulates*} + \text{heat content of wastewater solids*} \times \text{wt of solids*}\right) \div \left(\text{heat content of solid waste} \times \text{wt of solid waste}\right)\right]\right\} 100.0$$

$$\text{Percent heat released} = \left\{1 - \left[\frac{(945)\ (2{,}000)\ (500)}{(5{,}530)\ (2{,}000)\ (2{,}300)}\right]\right\} 100.0$$

$$\text{Percent heat released} = \left[1 - \left(\frac{9.45 \times 10^8}{254.4 \times 10^8}\right)\right] 100.0 = 96.3$$

$$\text{Percent volume reduction} = \left\{1 - \left[\left(\frac{\text{total wt of wet residue}}{\text{density of wet residue}} + \frac{\text{wt of particulates*}}{\text{density of particulates}} + \frac{\text{wt of wastewater solids*}}{\text{density of solids}}\right) \div \left(\frac{\text{total wt of solid waste "as received"}}{\text{density of solid waste}}\right)\right]\right\} 100.0$$

$$\text{Percent volume reduction} = \left\{1 - \left[\left(\frac{660.8 \times 2{,}000}{1{,}615}\right) \div \left(\frac{2{,}300 \times 2{,}000}{145}\right)\right]\right\} 100.0$$

$$\text{Percent volume reduction} = \left[1 - \left(\frac{817}{31{,}724}\right)\right] 100.0 = 97.4$$

*Not measured.

APPENDIX D

Example Calculations for the Products of Combustion

At the sampling point, the products of combustion are influenced by the burning rate, the elemental composition of the waste, the products of combustion at stoichiometric conditions, and the excess air. The calculations contained in this appendix show the method used to determine the products of combustion. The first step was to complete Table D-1. Initially, the pounds of each element per pound of waste, the burning rate of solid waste, the pounds of each element per pound of residue, the amount of residue per hour, and the pounds of oxygen required to burn a pound of each element were known. After calculating the pounds per hour of each element fed to the furnace as solid waste and the pounds per hour of each element remaining as residue, the table was completed by calculating the weight consumed of each element, the percent consumed, and the weight of the oxygen required to consume the total weight of each element consumed. The following calculations complete the determination of the combustion products.

Theoretical lb of O_2 required for oxidation of carbon . . .	20,256
Theoretical lb of O_2 required for oxidation of hydrogen . .	8,432
Theoretical lb of O_2 required for oxidation of sulfur . . .	15
Theoretical lb of O_2 required per element	28,703
Lb of O_2 available in waste	7,086
Theoretical lb of O_2 required	21,617

TABLE D-1

DETERMINATION OF COMBUSTION PRODUCTS

Element	Solid waste			Residue			Weight consumed		Oxygen required	
	lb element / lb waste	Burning rate (lb/hr)	Amount fed to furnace (lb/hr)	lb element / lb waste	weight (lb/hr)	Amount remaining as residue (lb/hr)	lb/hr	%	lb O_2 / lb element	lb/hr
Carbon	0.301	26,840	8,079	0.080	5,800	464	7,615	28.37	2.66	20,256
Hydrogen	0.040	26,840	1,074	0.002	5,800	12	1,062	3.96	7.94	8,432
Oxygen	0.264	26,840	7,086	0.000	5,800	0	7,086	26.40	*	*
Sulfur	0.001	26,840	27	0.002	5,800	12	15	0.06	1.00	15
Nitrogen	0.005	26,840	134	0.001	5,800	6	128	0.48	*	*
Moisture	0.210	26,840	5,636	0.000	5,800	0	5,636	21.00	*	*
Inerts	0.177	26,840	4,751	0.915	5,800	5,307	-556	-2.07	*	*
Chlorine	0.002	26,840	54	0.000	5,800	0	54	0.20	*	*

*Not applicable.

$$\frac{\text{lb } O_2}{\text{lb waste}} = \frac{21{,}617}{26{,}840} = 0.805$$

$$\frac{\text{lb air}}{\text{lb waste}} = \frac{0.805 \text{ lb } O_2}{\text{lb waste}} \div \frac{0.2315 \text{ lb } O_2}{\text{lb air}} = 3.479$$

The volume of the theoretical combustion products per pound of waste may be calculated by using the ideal gas law, which is

$$\text{Volume} = \frac{387m}{M}$$

The mass of each component per pound of waste may be calculated as follows:

$$m_{N_2} = \left(\frac{\text{lb } N_2}{\text{lb air}}\right)\left(\frac{\text{lb air}}{\text{lb waste}}\right) + \left(\text{wt } N_2 \text{ consumed}\right)$$

$$m_{O_2} = \text{excess}$$

$$m_{CO_2} = \left(\frac{\text{percent carbon consumed}}{100}\right)\left(\frac{3.66 \text{ lb } CO_2 \text{ produced}}{\text{lb carbon}}\right)$$

$$m_{H_2O \text{ fuel}} = \left(\frac{\text{percent hydrogen consumed}}{100}\right)\left(\frac{8.94 \text{ lb } H_2O \text{ produced}}{\text{lb hydrogen}}\right) + \frac{\text{percent } H_2O \text{ in fuel}}{100}$$

$$m_{H_2O \text{ excess air}} = \left(\frac{\text{lb air}}{\text{lb waste}} \quad \frac{0.0263 \text{ lb } H_2O}{\text{lb air}}\right)$$

These calculations are summarized in Table D-2.

TABLE D-2

DETERMINATION OF THEORETICAL COMBUSTION PRODUCTS

Theoretical combustion products	m	M	V
m_{N_2} = (0.7685)(3.479) + 0.0048	2.678	28	37.019
m_{CO_2} = (0.2837)(3.66)	1.038	44	9.133
m_{H_2O}, fuel = (0.0346)(8.94) + 0.21	*	*	*
m_{H_2O}, air = (3.479)(0.0263)	*	*	*
m_{O_2} = excess	0.000	32	0.000
Theoretical dry gas volume	---	---	46.152

*Not applicable.

$$\text{Theoretical Q} = \frac{46.152 \text{ scf}}{\text{lb waste}} \quad \frac{26{,}840 \text{ lb waste}}{\text{hr}} \quad \frac{\text{hr}}{60 \text{ min}}$$

Theoretical Q = 20,645 scf/min

Calculate combustion products for Stack Test No. 2 as follows:

Excess air (EA) = Actual Q minus Theoretical Q

EA = 88,878 - 20,645

EA = 68,233 scf/min

From the ideal gas law, 1 lb of excess air occupies 13.33 scf.

$$\frac{\text{lb EA}}{\text{min}} = \frac{68,233}{13.33} = 5,119$$

$$\frac{\text{lb EA}}{\text{lb waste}} = \left(\frac{5,119 \text{ lb EA}}{\text{min}}\right)\left(\frac{\text{hr}}{26,840 \text{ lb waste}}\right)\left(\frac{60 \text{ min}}{\text{hr}}\right)$$

$$\frac{\text{lb EA}}{\text{lb waste}} = 11.443$$

$$\text{Percent EA} = \left(\frac{\text{lb EA/lb waste}}{\text{lb air/lb waste}}\right) 100.0 = \left(\frac{11.443}{3.479}\right) 100.0 = 328.9$$

At 328.9 percent excess air, the total amount of air is 428.9 percent.

The theoretical amount of oxygen and air used is determined as follows:

$$\text{Total wt of } O_2 = 4.289 \left(\frac{0.805 \text{ lb } O_2}{\text{lb waste}}\right) = 3.453$$

$$\text{Total wt of air} = 4.289 \left(\frac{3.479 \text{ lb air}}{\text{lb waste}}\right) = 14.921$$

$$\text{Excess wt of } O_2 = 3.453 - 0.805 = 2.648$$

$$\text{Excess wt of air} = 14.921 - 3.479 = 11.442$$

Using 328.9 percent excess air, the calculations for the products of combustion are summarized in Table D-3.

If a 20 percent CO_2 reduction in the scrubber is assumed,[11] the composition (percent) of the combustion products is as follows:

$CO_2 = 4.57 - (0.2)(4.57) =$	3.66
$O_2 =$	16.04
$N_2 =$	79.39
Total	99.09

The corrected concentration (percent) is as follows:

CO_2 = (3.66 ÷ 99.09) 100.0 = 3.7

O_2 = (16.04 ÷ 99.09) 100.0 = 16.2

N_2 = (79.39 ÷ 99.09) 100.0 = 80.1

TABLE D-3

DETERMINATION OF COMBUSTION PRODUCTS FOR TEST NO. 2

Combustion product	m	M	V	%V
m_{CO_2} = (0.2837) 3.66	1.038	44	9.133	4.57
m_{H_2O} = (0.0396)(8.94) + 0.21 + (0.0263)(14.921)	*	*	*	*
m_{SO_2} = (0.0006) 2	0.001	64	0.000	0.00
m_{O_2} = excess	2.648	32	32.024	16.04
m_{N_2} = (0.7685)(14.921) + 0.0048	11.472	28	158.554	79.39
Total	---	---	199.711	100.00

*Not applicable.